

Constraining unparticle physics with CP violation in Cabibbo-favored decays of D mesons

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According to the standard model, the Cabibbo-favored (CF) decays are CP conserved at tree level. Observation of any finite CP asymmetry can be received as a signal of new physics. In CF charm meson decays, $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K_s^0\pi^+$, the following experimental values for their CP asymmetry are reported, respectively: $(0.3 \pm 0.7)\%$ and $(-0.41 \pm 0.09)\%$. The value of the later can be attributed to the mixing of K^0 and \bar{K}^0 , however, its contribution is about $(-0.332 \pm 0.006)\%$. In this paper, we use these experimental results to constrain the unparticle stuff as a new physics which may contribute to these CP asymmetries.

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I. INTRODUCTION

In the standard model (SM), CP violation comes from the complex valued nature of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, and in fact from a residual imaginary phase [1]. There are two types of CP violation: direct CP violation (CP violation in decay) and indirect CP violation (CP violation with mixing). In charged mesons (such as D^+), since there is no mixing with their anti-particles, only direct CP violation observes. The direct CP asymmetry for typical $D \rightarrow f$ decay is defined as:

$$A_{CP} = \frac{\Gamma(D \rightarrow f) - \Gamma(\bar{D} \rightarrow \bar{f})}{\Gamma(D \rightarrow f) + \Gamma(\bar{D} \rightarrow \bar{f})} = \frac{|A(D \rightarrow f)|^2 - |A(\bar{D} \rightarrow \bar{f})|^2}{|A(D \rightarrow f)|^2 + |A(\bar{D} \rightarrow \bar{f})|^2}, \quad (1)$$

where Γ and A are the partial decay width and decay amplitude, respectively. To have a CP violation, we need two amplitudes, A_1 and A_2 , with different CP -conserved phase and also different CP -violated phase. Rewriting

$A(\bar{D} \rightarrow \bar{f})$ as \bar{A} and defining $A_i = |A_i|e^{i(\phi_i+\delta_i)}$ and $\bar{A}_i = |A_i|e^{i(-\phi_i+\delta_i)}$, Eq. (1) can be written as

$$A_{CP} = \frac{|A|^2 - |\bar{A}|^2}{|A|^2 + |\bar{A}|^2} = \frac{2|A_1||A_2|\sin\Delta\phi\sin\Delta\delta}{|A_1|^2 + |A_2|^2 + |A_1A_2|\cos\Delta\phi\cos\Delta\delta}. \quad (2)$$

This equation also confirms that to have a nonvanishing CP violation in decay, two amplitudes with two nonzero CP -conserved and -violated phase differences are needed. For latter uses we introduce the ratio of A_1 and A_2 by $r_f = A_1/A_2$.

Historically, CP violation discovered and observed in 1964 for K mesons by Cronin and Fitch [2]. Then, it observed in many decays for B mesons (see for instance [3,4]). But in the standard model, for D mesons, CP violation is predicted to be very small, $\leq \mathcal{O}(0.1\%)$ [5]. In fact, this issue is also obvious from the CKM matrix which is, up to order λ^6 , written as

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + \frac{1}{2}A^2\lambda^5[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1 + 4A^2) & A\lambda^2 \\ A\lambda^3[1 - (\rho + i\eta)(1 - \frac{1}{2}\lambda^2)] & -A\lambda^2 + \frac{1}{2}A\lambda^4[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}A^2\lambda^4 \end{pmatrix} + \mathcal{O}(\lambda^6). \quad (3)$$

Since in D mesons we deal only with the first and second generations, the imaginary part of the relevant elements in the above matrix are of order λ^5 . There was also no experimental observation of CP violation for D mesons till 2012 when LHCb reported a CP asymmetry for this

meson's family [6], though the recent LHCb measurement shows no evidence for CP violation [7]. However, the large uncertainties which exist in these measurements allow one to assume a new physics (NP) beyond the SM for explaining a possible deviation from SM and(or) putting some constrains on the parameter space of such NP.

Unparticle is a subjective theory that Georgi introduced in 2007 [8]. In addition to the experimental searches [9–12], unparticle physics is widely considered in various

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topics of high energy physics, such as in cosmology [13–15], astronomy [16–18], neutrino oscillation [19] and even in solid state and atomic physics [20–26] etc. In particular, it is involved in the study of various decays and scatterings, beyond the SM [27–34]. Also many papers study the presence of unparticle in CP violation, such as [35–43]. The effect of unparticle physics on the mixing of $B^0 - \bar{B}^0$ and $D^0 - \bar{D}^0$ have been considered in [35] and [36], respectively. In Ref. [37] authors have been found that the phases in unparticle propagators have a great impact on CP violation. Also, authors of Ref. [39] found that the direct CP violation in the $B \rightarrow l\nu$ decay, which is zero in SM, can show up due to the CP conserving phase intrinsic in unparticle physics. The effect of unparticle physics on CP violation for decay $B^+ \rightarrow \tau^+\nu$ have been also considered by Zwicky [40].

In our discussion, unparticle physics contributes to one of the two amplitudes which are necessary for CP violation. Here, we first review the CP asymmetries for $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K_s^0\pi^+$ decays in the SM and consider their reported values from various experiments. The first decay is Cabibbo-favored (CF). The second is a combination of $D^+ \rightarrow \bar{K}^0\pi^+$ and $D^+ \rightarrow K^0\pi^+$ which are, respectively, CF and doubly-Cabibbo-suppressed (DCS) that is negligible. In the SM, for CF decays of D mesons there is only one amplitude with neither conserved-, nor violated-phase, so there is no predicted CP violation for such decays. Here, we implement unparticle stuff to contribute as a second amplitude which can give us both conserved- and violated-phase differences. Using these decays, we try to constrain the relevant parameter space of unparticle physics.

We organized the paper as follows: in Sec. II we study the $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K_s^0\pi^+$ decays in the SM briefly

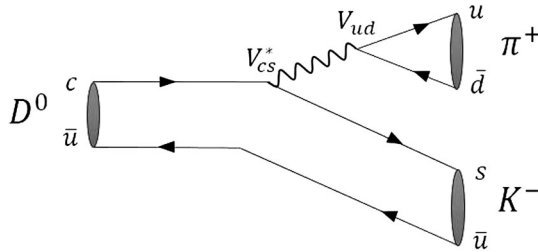
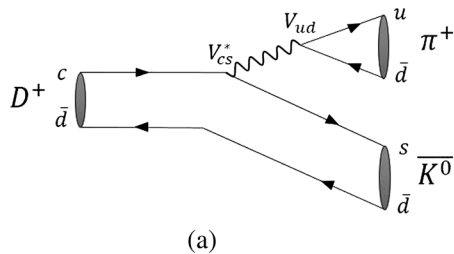
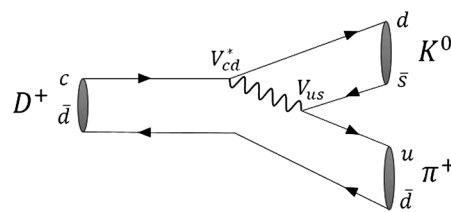


FIG. 1. Tree level $D^0 \rightarrow K^-\pi^+$ decay.



(a)



(b)

FIG. 2. Tree level $D^+ \rightarrow \bar{K}^0\pi^+$ (left) and $D^+ \rightarrow K^0\pi^+$ (right). The first diagram is CF and the second is DCS.

and review the various experimental works on them. Then the unparticle effects for these decays is considered in Sec. III. In the last section we conclude our results.

II. $D^0 \rightarrow K^-\pi^+$ AND $D^+ \rightarrow K_s^0\pi^+$ DECAYS IN THE STANDARD MODEL AND EXPERIMENT

A. $D^0 \rightarrow K^-\pi^+$ decay

The main contributions to this decay are the tree level quark contribution, exchange quark diagrams (box contribution) and color-suppressed quarks diagrams (di-penguins contribution). The tree level quark contribution is CF (see Fig. 1).

The direct CP asymmetry is then [44]

$$A_{CP}^{D^0 \rightarrow K^-\pi^+} \equiv \frac{\Gamma(D^0 \rightarrow K^-\pi^+) - \Gamma(\bar{D}^0 \rightarrow K^+\pi^-)}{\Gamma(D^0 \rightarrow K^-\pi^+) + \Gamma(\bar{D}^0 \rightarrow K^+\pi^-)} = 1.4 \times 10^{-10}, \quad (4)$$

where Γ is the partial decay width. Due to the very smallness of this value, observation of a CP violation for this decay can be a smoking gun of new physics.

Note that, the contribution of the indirect CP violation for this decay is negligible. The experimentally reported value for the CP asymmetry in this decay, accepted by PDG, is $A_{CP} = (0.3 \pm 0.7)\%$ [45].

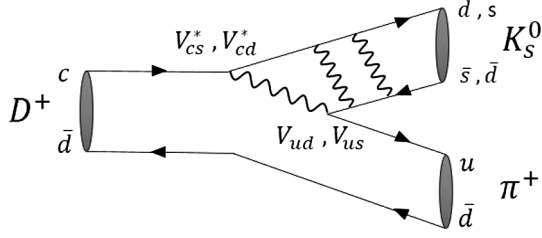
B. $D^+ \rightarrow K_s^0\pi^+$ decay

The first evidence of CP violation in charmed particles reached after the FOCUS [46], CLEO [47], Belle [48], and BABAR [49] measurements for the decay $D^+ \rightarrow K_s^0\pi^+$. The first world average for the CP asymmetry of this decay was $(-0.54 \pm 0.14)\%$. This decay is performed through two steps; initially D^+ decays to K^0 or \bar{K}^0 , then $K^0 \rightleftharpoons \bar{K}^0$ mixing occurs. For the CP asymmetry of this decay we have

$$A_{CP}^{D^+ \rightarrow K_s^0\pi^+} \equiv \frac{\Gamma(D^+ \rightarrow K_s^0\pi^+) - \Gamma(D^- \rightarrow K_s^0\pi^-)}{\Gamma(D^+ \rightarrow K_s^0\pi^+) + \Gamma(D^- \rightarrow K_s^0\pi^-)}. \quad (5)$$

One can write, by a simple calculation,

$$A_{CP}^{D^+ \rightarrow K_s^0\pi^+} \approx A_{CP}^{\Delta C} + A_{CP}^{\text{mixing}}, \quad (6)$$


 FIG. 3. $D^+ \rightarrow K_s^0 \pi^+$ with both DCS and CF amplitudes.

where $A_{CP}^{\Delta C}$ and A_{CP}^{mixing} denote CP asymmetries in the charm decay (ΔC) and in $K^0 \rightleftharpoons \bar{K}^0$ mixing in the SM, respectively [50,51].

Amplitudes of two processes contribute to this decay; $D^+ \rightarrow \bar{K}^0 \pi^+$ decay which is CF, Fig. 2(a), and $D^+ \rightarrow K^0 \pi^+$ decay which is DCS, Fig. 2(b). Mixing of K^0 and \bar{K}^0 in the final state leads to K_s^0 . The combination of these two scenarios have been shown in Fig. 3. On the other hand, for D decays, penguin diagrams, which we need for CP violation as a second amplitude, contribute only to the singly Cabibbo suppressed (SCS) decays. Hence, focusing on CF decays, we have no CP violation in charm sector. Consequently, all of the CP asymmetry in $D^+ \rightarrow K_s^0 \pi^+$ must be due to $K^0 \rightleftharpoons \bar{K}^0$ mixing, which is measured to be $(-0.332 \pm 0.006)\%$ from K_L^0 semileptonic decays ($K_L^0 \rightarrow \pi^- l^+ \nu$) [52]. The CP asymmetry values for this decay from various experiments are shown in Table I. The new world average reported by PDG is -0.41 ± 0.09 [53]. Therefore, comparing the mixing contribution reported from K_L^0 semileptonic decays, and the new world average, we see about $(-0.08 \pm 0.09)\%$ of asymmetry difference. Consequently, the contribution of any possible NP, such as unparticle, in CP asymmetry of charm sector should lie in this interval. Hereby, we can constrain the parameter space of unparticle stuff.

III. $D^0 \rightarrow K^- \pi^+$ AND $D^+ \rightarrow K_s^0 \pi^+$ WITH UNPARTICLE

In this section we first, briefly, review the unparticle physics which is a new scale invariant sector introduced firstly by Georgi [8]. The propagator of a scalar (vector) unparticle $O_{\mathcal{U}}^{(\mu)}$, is

 TABLE I. CP asymmetry for $D^+ \rightarrow K_s^0 \pi^+$ decay in different experiments [54].

Experiment	$A_{CP}^{D^+ \rightarrow K_s^0 \pi^+} (\%)$
FOCUS	$-1.6 \pm 1.5 \pm 0.9$
CLEO	$-1.3 \pm 0.7 \pm 0.3$
BABAR	$-0.44 \pm 0.13 \pm 0.10$
Belle	$-0.363 \pm 0.094 \pm 0.067$
New world average	-0.41 ± 0.09

$$\int d^4x e^{ip \cdot x} \langle 0 | T [O_{\mathcal{U}}^{(\mu)}(x) O_{\mathcal{U}}^{(\nu)}(0)] | 0 \rangle = \Delta_{\mathcal{U}}^{S(V)}(p^2) e^{-i\phi_{\mathcal{U}}}, \quad (7)$$

where

$$\Delta_{\mathcal{U}}^S(p^2) = \frac{A_{d_{\mathcal{U}}}}{2 \sin(d_{\mathcal{U}}\pi)} \frac{1}{(p^2 + i\epsilon)^{2-d_{\mathcal{U}}}},$$

$$\Delta_{\mathcal{U}}^V(p^2) = \frac{A_{d_{\mathcal{U}}}}{2 \sin(d_{\mathcal{U}}\pi)} \frac{-g^{\mu\nu} + p^\mu p^\nu / p^2}{(p^2 + i\epsilon)^{2-d_{\mathcal{U}}}}, \quad (8)$$

are the scalar and vector propagators, respectively. Here, $d_{\mathcal{U}}$ is the unparticle dimension, $\phi_{\mathcal{U}} = (2 - d_{\mathcal{U}})\pi$ and

$$A_{d_{\mathcal{U}}} = \frac{16\pi^{5/2}}{(2\pi)^{2d_{\mathcal{U}}}} \frac{\Gamma(d_{\mathcal{U}} + 1/2)}{\Gamma(d_{\mathcal{U}} - 1)\Gamma(2d_{\mathcal{U}})}. \quad (9)$$

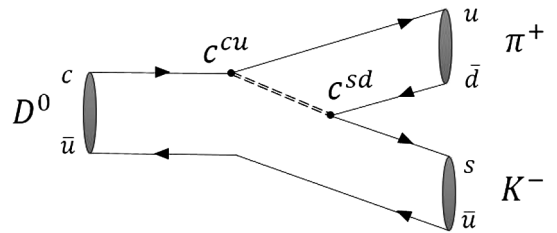
Then, the unparticle couplings with quarks will be given by the following effective Lagrangian:

$$\mathcal{L} = \frac{c_V^{q'q}}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}-1}} \bar{q}' \gamma_\mu (1 - \gamma_5) q O_{\mathcal{U}}^\mu + \frac{c_S^{q'q}}{\Lambda_{\mathcal{U}}^{d_{\mathcal{U}}}} \bar{q}' \gamma_\mu (1 - \gamma_5) q \partial_\mu O_{\mathcal{U}} + \text{H.c.}, \quad (10)$$

where $c_{S,V}^{q'q}$ are dimensionless parameters and $\Lambda_{\mathcal{U}}$ is an energy scale in which unparticles will appear. The first (second) term in this Lagrangian is related to the vector (scalar) unparticle. Unparticle with scale dimension $d_{\mathcal{U}}$ treats as nonintegral number $d_{\mathcal{U}}$ of invisible massless particle.

A. $D^0 \rightarrow K^- \pi^+$ decay with tree level unparticle amplitude

Now, we investigate the $D^0 \rightarrow K^- \pi^+$ decay with unparticle. As mentioned in Sec. II A, in the SM, this decay has only a CF amplitude at tree level with no penguin diagram. The unparticle diagram for this decay is shown in Fig. 4 (Here we consider an uncharged unparticle). This new amplitude can give us strong (CP -conserved) and weak (CP -violated) phase differences needed for CP violation. The total amplitude now becomes


 FIG. 4. $D^0 \rightarrow K^- \pi^+$ with unparticle.

$$A_{\text{total}}^{K^-\pi^+} = A_{\text{SM}}^{K^-\pi^+} + A_{\mathcal{U}}^{K^-\pi^+} = A_{\text{SM}}^{K^-\pi^+} (1 + r_{K^-\pi^+} e^{-i\phi_{\mathcal{U}}} e^{-i\phi_W}), \quad (11)$$

where ϕ_W and $\phi_{\mathcal{U}} = (d_{\mathcal{U}} - 2)\pi$ are CP -violated and CP -conserved phase differences, respectively (knowing that the SM phases are zero). Here, $A_{\text{SM}}^{K^-\pi^+}$ is the SM amplitude [40]

$$A_{\text{SM}}^{K^-\pi^+} = \frac{G_F}{\sqrt{2}} V_{cs}^* V_{ud} \mathcal{F}, \quad (12)$$

and $r_{K^-\pi^+}$ is the ratio of unparticle and SM amplitudes,

$$r_{K^-\pi^+} = \frac{8}{g^2 a_1 N_c} \frac{|c_V^{cu} c_V^{sd}|}{|V_{cs}^* V_{ud}|} \frac{A_{d_{\mathcal{U}}}}{2 \sin(d_{\mathcal{U}}\pi)} \frac{m_W^2}{p^2} \left(\frac{p^2}{\Lambda_{\mathcal{U}}^2} \right)^{d_{\mathcal{U}}-1}, \quad (13)$$

where \mathcal{F} is a function which depends on the meson mass and QCD detail, that finally removed in Eq. (2). Here, $a_1 = C_2 + C_1/N_c$ is the effective Wilson coefficient [55], N_c is the color number and $p^2 \sim m_D \bar{\Lambda}$ with $\bar{\Lambda} = m_D - m_c$. We can ignore the scalar unparticle contributions, since they are suppressed by $m_D^2/\Lambda_{\mathcal{U}}^2$. Therefore, the Eq. (2) becomes

$$A_{\text{CP}}^{K^-\pi^+} = \frac{2r_{K^-\pi^+} \sin(d_{\mathcal{U}}\pi) \sin\phi_W}{1 + r_{K^-\pi^+}^2 + 2r_{K^-\pi^+} \cos d_{\mathcal{U}}\pi \cos\phi_W}. \quad (14)$$

Note that, in this case, as we mentioned before, up to order λ^4 in the Wolfenstein CKM matrix there is no CKM weak phase and here ϕ_W (CP -violated phase) comes completely from the complex valued nature of unparticle couplings.

Here, we try to illustrate the role of the various parameters in some figures in such a way $A_{\text{CP}}^{D^0 \rightarrow K^-\pi^+} = (0.3 \pm 0.7)\%$. There are, in principle, four independent parameters: the unparticle scale $\Lambda_{\mathcal{U}}$, the scaling dimension $d_{\mathcal{U}}$, the net resultant phase of the coupling constants ϕ_W , the absolute value of couplings product, $|c_V^{cu} c_V^{sd}|$. We fix the scale of unparticle $\Lambda_{\mathcal{U}}$ about 15 TeV, due to the recent energy achievement in LHC. The dependence of A_{CP} to $|c_V^{cu} c_V^{sd}|$ is also trivial (linear), in the regime where we expect the perturbation works and also corrections to the SM are small.¹ Therefore the main parameters which may play important roles are ϕ_W and $d_{\mathcal{U}}$.

In Fig. 7, we have plotted A_{CP} in terms of $d_{\mathcal{U}}$ for two different $\phi_W = \pm 0.07$. In this figure, the allowed region has been colored and we have fixed $|c_V^{sd} c_V^{cu}| \approx 10^{-5}$. This figure shows that for some regions, around $d_{\mathcal{U}} = 1.15$, A_{CP} is larger than all allowed values. Since the weak and strong phases play important roles in CP violation, we try to study the related parameter space for some various values of product $|c_V^{sd} c_V^{cu}|$ through contour plots of Fig. 8. In these contour plots the vertical axes shows the weak phase, and the horizontal axes is devoted to dimension of the

¹The upper bound of c_V^{cu} have been fixed from $D^0 \rightleftharpoons \bar{D}^0$ mixing at $|c_V^{cu}| < 5 \times 10^{-4}$ for $d_{\mathcal{U}} = 3/2$ [36].

unparticle $d_{\mathcal{U}}$ which determines the strong phase. Here, the color shows the A_{CP} .

As a result of this figure, in $\Lambda_{\mathcal{U}} = 15$ TeV, there exist some regions which are excluded by this process for $|c_V^{sd} c_V^{cu}| \sim 10^{-5}$, while in the case of $|c_V^{sd} c_V^{cu}| \sim 10^{-6}$, or weaker couplings, the whole of parameter space is allowed. In other words, for $|c_V^{sd} c_V^{cu}| \approx 10^{-5}$ as well as stronger couplings, the unparticle physics contribution can be explored by experimental test which is more accurate than the recent data while for the values less than about 10^{-5} , it is far from recent precisions and is not testable.

B. $D^+ \rightarrow K_s^0 \pi^+$ decay with tree level unparticle amplitude

Here in this section, we apply unparticle theory as a second amplitude to explain the $(-0.08 \pm 0.09)\%$ CP asymmetry related to the charm sector. As mentioned before, this value is due to the difference between the world average CP asymmetry for $D^+ \rightarrow K_s^0 \pi^+$ decay and the corresponding value for $K^0 \rightleftharpoons \bar{K}^0$ mixing ($A_{\text{CP}}^{\text{mixing}}$).

Again, for this decay we have no penguin diagram and in tree level it has both CF and DCS amplitudes which we neglect DCS one [56]. Unparticle stuff can give a diagram which leads to the strong and weak phase differences between two amplitudes (corresponding to SM and unparticle). One could see the diagram of $D^+ \rightarrow \bar{K}^0 \pi^+$ and $D^+ \rightarrow K_s^0 \pi^+$ with unparticle in Figs. 5 and 6, respectively.

This decay is the same as $D^0 \rightarrow K^-\pi^+$, if one changes the observer quark \bar{u} to \bar{d} and also adds a $K^0 \rightleftharpoons \bar{K}^0$ mixing in final state. To write the total A_{CP} we note that, we are seeking for a CP asymmetry in addition to the contribution of SM mixing, as mentioned before. Moreover, the

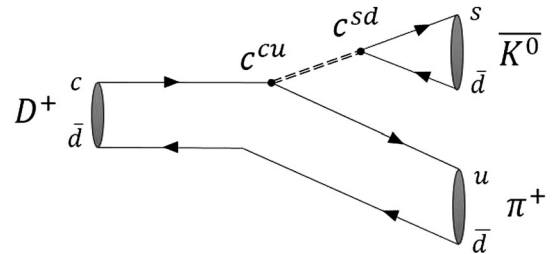


FIG. 5. $D^+ \rightarrow \bar{K}^0 \pi^+$ decay with unparticle.

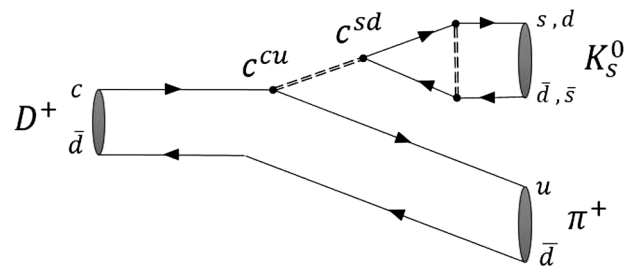


FIG. 6. $D^+ \rightarrow K_s^0 \pi^+$ decay with unparticle.

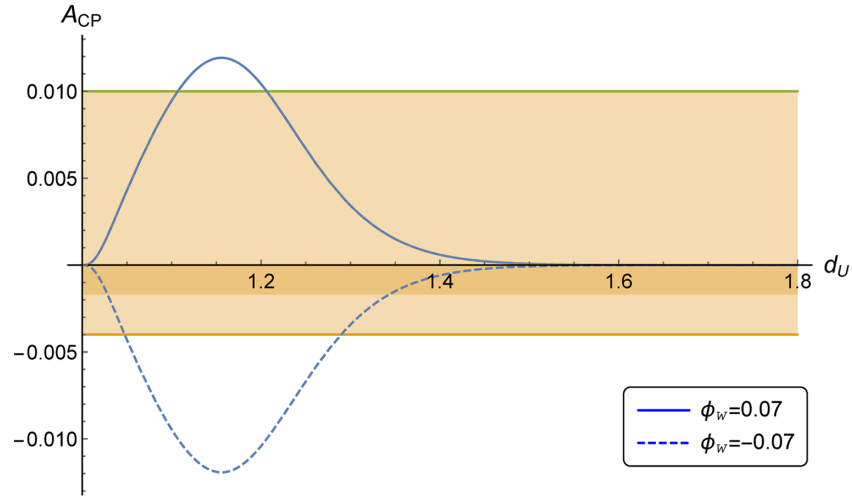


FIG. 7. A_{CP} (due to the charm sector) in terms of d_U , for $\Lambda_U = 15$ TeV, $|c_V^{sd} c_V^{cu}| \approx 10^{-5}$, $\phi_W = 0.07$ (solid line) and $\phi_W = -0.07$ (dashed line). The dark region is related to the experimental bound for CP asymmetry for $D^0 \rightarrow K^- \pi^+$ decay and the darker one for $D^+ \rightarrow K_s^0 \pi^+$ decay.

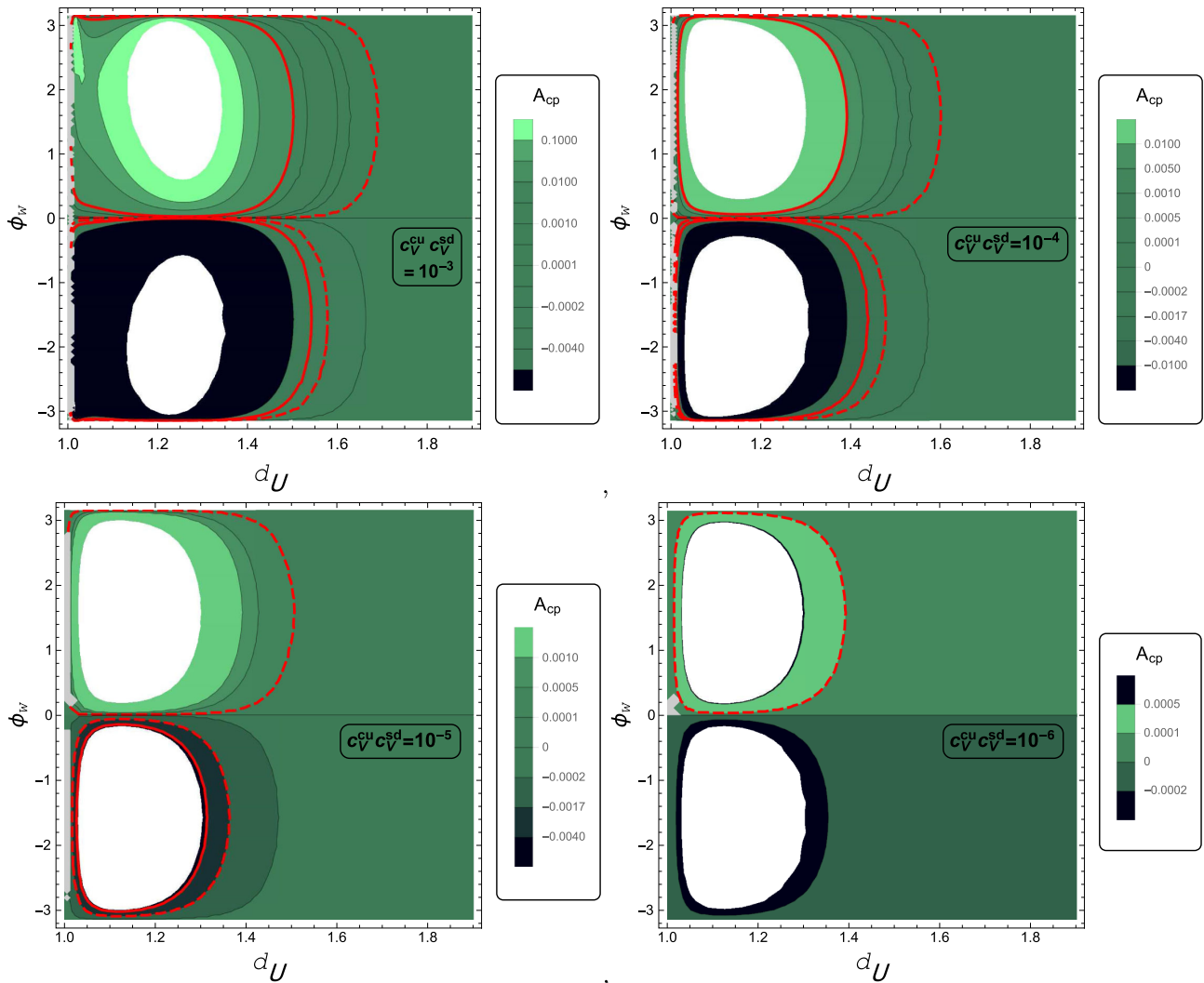


FIG. 8. A_{CP} (color) for $D^0 \rightarrow K^- \pi^+$ and also for charm sector of $D^+ \rightarrow K_s^0 \pi^+$ with respect to ϕ_W and d_U for different values of $|c_V^{sd} c_V^{cu}|$. The red solid (dashed) lines denotes the recent bounds on CP asymmetry for the first (second) decay.

unparticle contribution in $K^0 \rightleftharpoons \bar{K}^0$ mixing is negligible [29]. Therefore, the total amplitude becomes

$$\begin{aligned} A_{\text{total}} &= A_{\text{SM}}^{\bar{K}^0\pi^+} + A_{\mathcal{U}}^{\bar{K}^0\pi^+} \\ &= A_{\text{SM}}^{\bar{K}^0\pi^+} (1 + r_{\bar{K}^0\pi^+} e^{-i\phi_{\mathcal{U}}} e^{-i\phi_W}), \end{aligned} \quad (15)$$

where

$$A_{\text{SM}}^{\bar{K}^0\pi^+} = \frac{G_F}{\sqrt{2}} V_{cs}^* V_{ud} \mathcal{F}', \quad (16)$$

and

$$r_{\bar{K}^0\pi^+} = \frac{8}{g^2 a_1 N_c} \frac{|c_V^{cu} c_V^{sd}|}{|V_{cs}^* V_{ud}|} \frac{A_{d_{\mathcal{U}}}}{2 \sin(d_{\mathcal{U}}\pi)} \frac{m_W^2}{p^2} \left(\frac{p^2}{\Lambda_{\mathcal{U}}^2} \right)^{d_{\mathcal{U}}-1}, \quad (17)$$

where \mathcal{F}' is defined similar to \mathcal{F} . Consequently, the direct CP asymmetry becomes

$$A_{\text{CP}} \approx A_{\text{CP}}^{\text{mixing}} + \frac{2r_{\bar{K}^0\pi^+} \sin(d_{\mathcal{U}}\pi) \sin\phi_W}{1 + r_{\bar{K}^0\pi^+}^2 + 2r_{\bar{K}^0\pi^+} \cos d_{\mathcal{U}}\pi \cos\phi_W}. \quad (18)$$

As it is obvious from the above equation, the second term in the right-hand side is exactly the same as Eq. (14). Therefore, our general phenomenological discussion do not alter, however, here we should be careful about the allowed regions in parameter space (see Figs. 7 and 8). In particular, according to Fig. 8, for $|c_V^{sd} c_V^{cu}| \sim 10^{-6}$, while the whole region is allowed in the case of first process, some region with positive value of A_{CP} is excluded by the recent process.

IV. CONCLUSIONS

The new world averages for CP violation in $D^0 \rightarrow K^- \pi^+$ and $D^+ \rightarrow K_s^0 \pi^+$ decays reported by PDG are $(0.3 \pm 0.7)\%$ and $(-0.41 \pm 0.09)\%$ respectively. In $D^+ \rightarrow K_s^0 \pi^+$, the value $(-0.332 \pm 0.006)\%$ is due to the mixing of K^0 and \bar{K}^0 mesons in the final state. Subtracting this contribution, one can conclude that any possible NP gives, at most, a CP asymmetry in the interval $(-0.08 \pm 0.09)\%$. Interaction between a scale invariant sector, called unparticle by Georgi [8], and the SM fields, as a NP, can induce a CP asymmetry [37].

In this paper, we have studied the unparticle induced CP asymmetry in both processes $D^0 \rightarrow K^- \pi^+$ and $D^+ \rightarrow K_s^0 \pi^+$ decays. More explicitly, both phase differences (weak and strong), needed for CP violation, come from unparticle diagrams. Note that, these two decays are CF (in charm sector), which has no predicted CP asymmetry in the SM at tree level. Here, in addition to the scale of unparticle physics $\Lambda_{\mathcal{U}}$, three important parameters play role; the net resultant weak phase of unparticle ϕ_W , the dimension of unparticle $d_{\mathcal{U}}$ which determines the strong phase and the product of couplings $|c_V^{sd} c_V^{cu}|$. The CP asymmetry with respect to the $d_{\mathcal{U}}$ for a fixed value of ϕ_W and $|c_V^{sd} c_V^{cu}|$ is plotted for $\Lambda_{\mathcal{U}} = 15$ TeV in Fig. 7. With choosing $\phi_W = \pm 0.2$ and $|c_V^{sd} c_V^{cu}| = 10^{-5}$, for instance, the absolute value of CP asymmetry gets a maximum in $d_{\mathcal{U}} \sim 1.2$, in which the CP asymmetry exceeds of experimental bounds. We have also demonstrated the parameter space of this theory through some contour plots for $\Lambda_{\mathcal{U}} = 15$ TeV and various values of $|c_V^{sd} c_V^{cu}|$. We see excluded regions in all selected $|c_V^{sd} c_V^{cu}|$, which correspond to the pick regions of CP asymmetry diagram.

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